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Evaluation of Methods for Simultaneous Collection and Determination of Nicotine and Polynuclear Aromatic Hydrocarbons in Indoor Air

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16. ABSTRACT

A study was performed to determine whether one sampling system and one analytical method can be used to measure both polynuclear aromatic hydrocarbons (PAH) and nicotine. The PAH collection efficiencies for both XAD-2 and XAD-4 adsorbents are very similar, but the nicotine collection efficiency was greater for XAD-4. The spiked perdeuterated PAH were retained well in both adsorbents after exposure to more than 300 m^3 of air. A two-step Soxhlet extraction, dichloromethane followed by ethylacetate, was used to remove nicotine and PAH from XAD-4. The extract was analyzed by positive chemical ionization or electron impact gas chromatography/mass spectrometry (GC/MS) to determine nicotine and PAH. It is shown that one sampling system (quartz fiber filter and XAD-4 in series) and one analytical method (Soxhlet extraction and GC/MS) can be used to measure both nicotine and PH in air.

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Evaluation of Methods for Simultaneous Collection and Determination of Nicotine and Polynuclear Aromatic Hydrocarbons in Indoor Air

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■ A study was performed to determine whether one sampling system and one analytical method can be used to collect and measure both polynuclear aromatic hydrocarbons (PAHs) and nicotine. PAH collection efficiencies for both XAD-2 and XAD-4 adsorbents were very similar, but nicotine collection efficiency was greater for XAD-4. Spiked perdeuterated PAHs were retained well in both adsorbents after exposure to more than 300 m^3 of air. A two-step Soxhlet extraction, dichloromethane followed by ethyl acetate, was used to remove nicotine and PAHs from XAD-4. The extract was analyzed by positive chemical ionization or electron impact gas chromatography/mass spectrometry (GC/MS) to determine nicotine and PAHs. It is shown that one sampling system (quartz fiber filter and XAD-4 in series) and one analytical method (Soxhlet extraction and GC/MS) can be used for both nicotine and PAHs in indoor air.

Introduction

Among the polynuclear aromatic hydrocarbons (PAHs) are found many compounds that can or might act as mutagens or carcinogens (*1–3*). Concern is increasing over our exposure to these compounds in indoor air in workplaces, homes, and schools because most of us spend more than 80% of our time indoors.

Several studies have identified environmental tobacco smoke (ETS) as a major contributor to PAH levels in indoor air. Two of our pilot studies of residential indoor air (*4, 5*) showed that indoor benzo[*a*]pyrene concentrations were ~10 times higher in a heavy smoker's home than those in a nonsmoker's home. The results from those pilot studies also showed that airborne concentrations of particulate matter and extractable organic matter are higher in homes occupied by smokers. Higher particle concentrations have been obtained in other studies of rooms occupied by smokers (*6, 7*). Several research groups (*2, 8, 9*) note that cigarette smoking can substantially increase the mutagenicity of indoor air samples.

Because nicotine is unique to tobacco and is a major constituent of its smoke, it is often used as a marker for ETS. Simultaneous determination of PAHs and nicotine in indoor air would permit assessment of the correlation between smoking, nicotine, and PAHs. The sampling methods (*4, 10*) used for indoor PAHs, to our knowledge,

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have not been used for nicotine. Different collection systems, such as treated filters that require separate sampling, preparation, and analysis, have been used to determine nicotine in air (*11*, *12*).

It has been demonstrated that nicotine is predominantly present in the vapor phase in ETS (*13*, *14*). Although XAD-2 resin has been used frequently to collect PAH vapors (*4*, *5*, *15*, *16*), it is not clear whether XAD-2 can collect nicotine vapors effectively in high concentrations of ETS. In one study (*17*) XAD-4 resin was used to collect nicotine in aircraft cabins, but the use of XAD-4 for collection of PAHs has not yet been demonstrated. Both XAD-2 and XAD-4 are styrene–divinylbenzene polymers, but XAD-4 has about twice the surface area of XAD-2. The use of XAD-4 to collect vapor-phase PAHs in air, however, has not been reported in the literature. Because we expect XAD-4 to collect PAHs at least as well as XAD-2, we investigated the use of XAD-4 resin to collect both PAH and nicotine vapors in indoor air. Note that we used quartz fiber filters in series with XAD-2 or XAD-4 traps to collect total PAHs and nicotine. The components that collected on the backup traps included vapor-phase PAHs and nicotine, as well as the reevaporation of particle-bound PAHs and nicotine. The discussion of phase distribution of PAHs was published elsewhere (*18*). Below we describe our development of the optimum analytical procedures to concurrently collect PAHs and nicotine for analysis using XAD-4 and our comparison of the effectiveness of XAD-2 and XAD-4 in sampling PAHs and nicotine indoors in the presence and absence of ETS.

Experimental Procedures

Adsorbent Preparation. We purchased XAD-2 and XAD-4 as precleaned resins from Supelco, Bellefonte, PA. The XAD-2 was further cleaned by Soxhlet extraction with dichloromethane (DCM) for 16 h and dried with a nitrogen gas stream. The clean XAD-2 resin was then packed in a PS-1 glass cartridge (General Metal Works, Cleves, OH) to a bed depth of 5 cm (*15*). The XAD-4 resin produced high background levels of naphthalene after Soxhlet extraction with DCM. We used various combinations of solvents to clean the XAD-4 by Soxhlet extraction and found that naphthalene removal required consecutive 16-h extractions with methanol, ethyl acetate, and DCM. The clean XAD-4 resin was dried and packed as above.

Sampling Method. A pair of newly developed prototype indoor air samplers, which are quiet and portable (*16*), one using XAD-2 and the other using XAD-4, were run simultaneously on 5 sampling days in an office at Battelle in the presence and absence of ETS. The ETS was generated by permitting cigarettes to burn in the laboratory; thus no "mainstream" smoke was present in this artificial ETS. A quartz fiber filter (104-mm QAST, Pallflex, Putnam, CT) was located upstream of the adsorbent in all the sampling experiments. Prior to sampling, both adsorbent cartridges were spiked with 80 μL of a DCM solution containing 2.0 μg of each of the compounds, [$^2H_8$]naphthalene, [$^2H_{10}$]phenanthrene, [$^2H_{12}$]chrysene, [$^2H_{12}$]benzo[*a*]pyrene, and [$^2H_3$]nicotine.

Air was sampled for approximately 24 h at a flow rate of 230 L/min. The total air sampled during the 24-h period represents 5.5% of the total air flow through the room. The samplers were exposed to ETS during the sampling period at uneven intervals for the first four experiments. In each experiment, a total of 25 cigarettes (Marlboro) was lit and allowed to burn to their filter tips. The tray containing the cigarettes was located ~2 m from both sampler inlets. In the fifth run, the samplers were not exposed to ETS.

Table I. Solvents Evaluated in XAD-4 Extraction Efficiency Study

method	solvent combinations[a]
solvent spike	dichloromethane
	0.01% trimethylamine in dichloromethane
	ethyl acetate
	0.01% trimethylamine in ethyl acetate
matrix spike	dichloromethane
	ethyl acetate
	0.01% trimethylamine in ethyl acetate
	0.01% pyridine in ethyl acetate
	dichloromethane followed by 0.01% pyridine in ethyl acetate
	dichloromethane followed by ethyl acetate

[a] Single-solvent extractions were carried out for 16 h. For two-step extractions, the extraction time was 16 h for the first solvent and 8 h for the second solvent.

Adsorbent Extraction Method. Two spiking methods were used for the solute spike. In the solvent-spike method, 200 μL of spiking solution containing naphthalene, acenaphthylene, phenanthrene, anthracene, pyrene, fluoranthene, benz[*a*]anthracene, chrysene, benzo[*a*]pyrene (25 ng/μL each), and nicotine (50 ng/μL) in DCM was injected into the solvent reservoir before extraction. In the matrix-spike method, 200 μL of the same spiking solution was injected into clean XAD-4 resin at a bed depth of 2.5 cm before extraction. After spiking, the extractions were carried out with different solvent combinations, shown in Table I, to determine the solvent system that best recovered PAHs and nicotine. All glassware was rinsed with 1% pyridine in DCM to minimize the loss of nicotine to glass surfaces. The XAD-2 and XAD-4 samples collected from indoor air sampling were extracted with DCM for 16 h, followed by ethyl acetate for 8 h. All extracts were concentrated to 1 mL by Kuderna–Danish (K–D) evaporation for subsequent analysis.

GC/MS Analysis Method. The extracts from the solvent-spiking and matrix-spiking experiments were analyzed by 70-eV electron impact (EI) gas chromatography/mass spectrometry (GC/MS). An Extranuclear MS equipped with a Hewlett-Packard GC Model 5710A was used. The data acquisition and processing were performed with an INCOS 2300 data system. The GC column was an Ultra No. 2 fused-silica capillary column (30-m length, 0.31-mm i.d., 0.17-μm film thickness; Hewlett-Packard Co.), and the column outlet was located in the MS ion source. Helium was used as the GC carrier gas. Following injection, the GC was held at 60 °C for 2 min and temperature programmed to 290 °C at 8 °C/min. The MS was scanned from 45 to 400 amu at 1 s/scan. An aliquot (200 μL) of the spiking solution was diluted to 1 mL with DCM and used as a calibration standard. Two internal standards were used, [$^2H_3$]nicotine for nicotine and 9-phenylanthracene for the PAHs. The internal standards were added to the standard solution and sample extracts at a constant concentration of 10 ng/μL. Identifications of target compounds were based on the correct mass spectra and correct retention times relative to the corresponding internal standards. The average response factor for each target compound was generated from the analyses of the standard solution. Quantifications of target compounds were based on comparisons of the respective integrated ion current responses for the molecular ions to those of the corresponding internal standards with average response factors.

The XAD-2 and XAD-4 extracts from the indoor sampling tests were analyzed by 150-eV positive chemical ionization (PCI) with selected ion monitoring (SIM). A

Table II. Recovery Data for PAHs and Nicotine from Extraction Solvent Spike Study

compound	% recovery[a]			
	DCM[b]	0.01% TMA in DCM[c]	EA[b]	0.01% TMA in EA[d]
naphthalene	88, 100	NA	100, 100	73
nicotine	100, 93	NA	120, 100	81
acenaphthylene	85, 93	NA	95, 74	96
phenanthrene	93, 95	NA	100, 100	99
anthracene	95, 87	NA	100, 93	100
fluoranthene	91, 91	NA	91, 90	99
pyrene	90, 94	NA	89, 90	100
benz[a]anthracene	100, 90	NA	80, 85	100
chrysene	100, 89	NA	81, 83	100
benzo[a]pyrene	100, 88	NA	100, 95	96

[a] Abbreviations: DCM, dichloromethane; TMA, trimethylamine; EA, ethyl acetate. [b] Duplicate experiments were performed. [c] The recovery data are not available (NA) due to formation of white precipitates during concentration. [d] Only one experiment performed.

standard Finnigan 4500 GC/MS with INCOS 2300 data system was used. The GC column was an Ultra No. 2 fused-silica capillary column (50-m length, 0.31-mm i.d., 0.51-μm film thickness; Hewlett-Packard Co.). The GC temperature programs were the same as described above. Methane was used as the GC carrier gas and reagent gas. The ion source pressure for the MS was 0.9 Torr at 60 °C GC column temperature. Since [$^2H_3$]nicotine was used in the spiking solution used in the air sampling tests, only one internal standard, 9-phenylanthracene, was used to quantify both nicotine and PAHs. A standard solution containing all the target compounds was prepared at 2 ng/μL except for nicotine at 5 ng/μL. The internal standard was added to samples and the standard solution at 1 ng/μL. Identifications of target compounds were based on the GC retention times of the individual monitored protonated molecular ion signals relative to that of the internal standard. Quantifications of target compounds were performed as described previously.

Results and Discussion

Extraction efficiencies for nicotine and PAHs from XAD-4 are presented in Tables II (solvent spike) and III (matrix spike). We did not evaluate the extraction efficiency from XAD-2 because we have demonstrated that DCM can quantitatively remove PAH from XAD-2 in other studies (*4*, *15*). In addition, XAD-2 and XAD-4 are similar types of adsorbents. We therefore assumed that if the solvent system could quantitatively remove nicotine and PAHs from XAD-4, it would also remove them from XAD-2. Greater than 80% recoveries were obtained for solvent-spiked PAHs and for solvent-spiked nicotine when either DCM or ethyl acetate was used as the extracting solvent, showing that loss of target compounds through extraction and concentration was negligible. White precipitates formed during the concentration of 0.01% trimethylamine in DCM, presumably ammonium salts formed from a reaction between trimethylamine and DCM. Therefore this solvent system was excluded from the matrix spike experiment.

The results from the matrix spike, given in Table III, show that when DCM was the extracting solvent, good PAH recoveries were obtained from the XAD-4, but only 27% of the nicotine was recovered. Because nicotine is very polar, DCM alone cannot remove nicotine from the XAD-4. The recovery of nicotine did improve to greater than 90% with the more polar solvent, ethyl acetate, but acenaphthylene and anthracene were recovered at only 60–70%. Therefore, two-step extractions were evaluated. These consisted of DCM followed by either 0.01% pyridine in ethyl acetate or 100% ethyl acetate. Good PAH and nicotine recoveries were achieved with these consecutive extractions. Note that naphthalene recoveries were greater than 100% in some cases because the extraction efficiency study and the evaluation of XAD-4 cleanup were conducted concurrently. Background levels of naphthalene present in XAD-4 were ~1–2 μg per each XAD-4 cartridge if the proper cleanup method was not used.

The PAH and nicotine levels collected on the XAD-2 and XAD-4 are shown in Figure 1. Since the nicotine present in ETS has been shown to be mostly in the vapor phase (*13*, *14*), the filter samples from this study were not analyzed. Note that average PAH concentrations from the first four experiments were displayed in Figure 1 as designated under smoking conditions. Only one experiment was conducted under nonsmoking conditions. As shown in Figure 1, the average PAH levels found with XAD-2 and XAD-4 are very similar to each other whether or not ETS is present. For example, the average phenanthrene concentrations from the first four experiments were 220 ng/m^3 from both XAD-2 and XAD-4; the phenanthrene concentrations from the fifth experiment were 80 ng/m^3 from XAD-2 and 78 ng/m^3 from XAD-4. This finding suggests that XAD-2 and XAD-4 have very similar sampling collection efficiency for PAHs. However, levels of nicotine found in XAD-4 samples were higher than those found in the corresponding XAD-2 samples. This can be seen in Table IV, which contains the results of a linear regression analysis of the concentrations of the compounds determined with the two adsorbents from all five experiments. The slope of the line of best fit, b, differs little from unity

Table III. Recovery of PAHs and Nicotine from Extraction Matrix Spike Study

compound	% recovery					
	DCM[b]	EA[b]	0.01% TMA in EA[b]	0.01% Pyr in EA[c]	DCM, then 0.01% Pyr in EA[c]	DCM, then EA[c]
naphthalene	>100[d]	>100[d]	>100[c]	96	100	100
nicotine	34, 20	98, 120	110, 110	100	85	95
acenaphthylene	95, 96	62, 65	63, 66	79	76	85
phenanthrene	97, 100	96, 110	100, 100	88	86	100
anthracene	91, 95	72, 75	74, 72	80	80	94
fluoranthene	91, 92	90, 99	91, 93	88	92	100
pyrene	91, 92	86, 99	90, 93	75	92	100
benz[a]anthracene	91, 94	83, 100	85, 93	80	90	100
chrysene	89, 97	83, 100	84, 83	75	92	100
benzo[a]pyrene	97, 97	60, 81	83, 82	64	93	100

[a] Abbreviations: DCM, dichloromethane; EA, ethyl acetate; TMA, trimethylamine; Pyr, pyridine. [b] Duplicate experiments were performed. [c] Only one experiment performed. [d] High background levels of naphthalene found in XAD-4 resin.

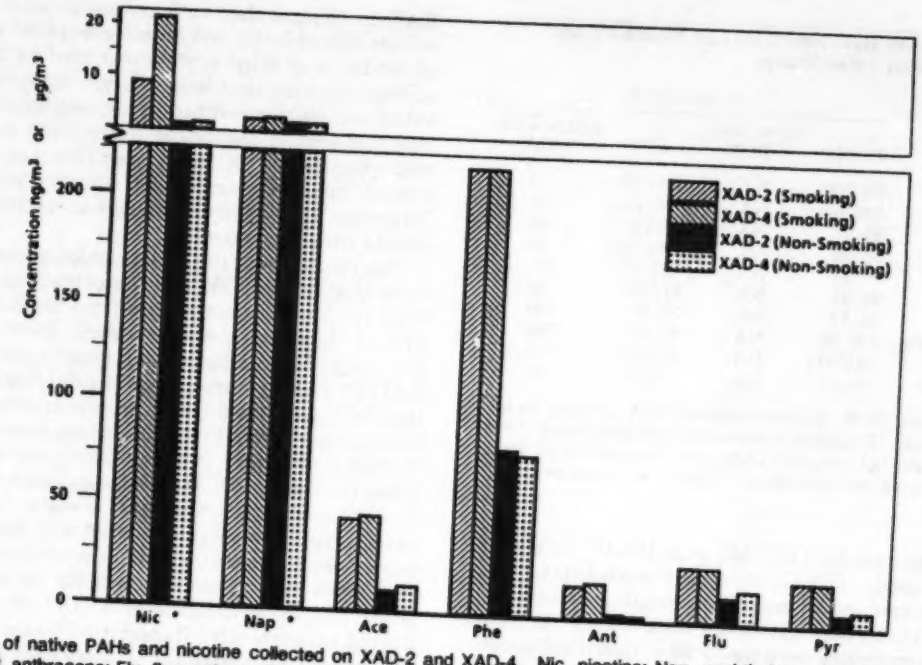

Figure 1. Levels of native PAHs and nicotine collected on XAD-2 and XAD-4. Nic, nicotine; Nap, naphthalene, Ace, acenaphthylene; Phe, phenanthrene; Ant, anthracene; Flu, fluoranthene; Pyr, pyrene. Vertical bars represent either the average concentrations from four experiments under smoking conditions or the single measurement from one experiment under nonsmoking conditions. Concentrations of nicotine and naphthalene are expressed as $\mu g/m^3$ and the remaining compounds as ng/m^3.

Table IV. Coefficients Determined for Regression Equation[a]

compound	a	b	r^2
nicotine	7900	1.8	0.72
acenaphthylene	5.8	0.93	0.69
phenanthrene	14	0.90	0.94
anthracene	−0.94	1.2	0.91
fluoranthene	3.3	0.86	0.88
pyrene	1.1	0.95	0.84
benz[a]anthracene	−0.40	1.4	0.83
chrysene	0.26	0.92	0.80

[a] [XAD-4] = a + b[XAD-2]. Brackets denote concentration of compound determined with the designated adsorbent. Five data points obtained for each adsorbent from all five experiments were used in the linear regression analysis.

for all PAHs (with the exception of benz[a]anthracene), and the correlation coefficients are generally high. This indicates that, with one unexplained exception, the two sorbents perform nearly equivalently for PAHs. For nicotine, however, the XAD-4 samples indicate nearly twice the concentration determined from the XAD-2 samples.

Indoor PAHs levels are at least an order of magnitude lower than nicotine levels; therefore, the collection capacity for PAHs of the adsorbents may not be saturated and similar PAHs levels were obtained with both adsorbents. Higher levels of PAHs and nicotine were found in room air that contained ETS. As shown in Figure 2, greater than 85% recoveries (86–110%) are obtained for all but [$^2H_{12}$]benzo[a]pyrene-spiked PAHs from both adsorbents. The average recoveries of [$^2H_{12}$]benzo[a]pyrene from the first four experiments under smoking conditions were 95% from XAD-2 and 97% from XAD-4; those recoveries from the fifth experiment under nonsmoking conditions were 79% from XAD-2 and 86% from XAD-4. Even though the PAH levels used in the spiking were higher than typical ambient levels of some PAHs, we did perform a study to demonstrate that XAD-2 can retain all ambient and indoor PAHs at indoor sampling temperature (21 °C) and summer

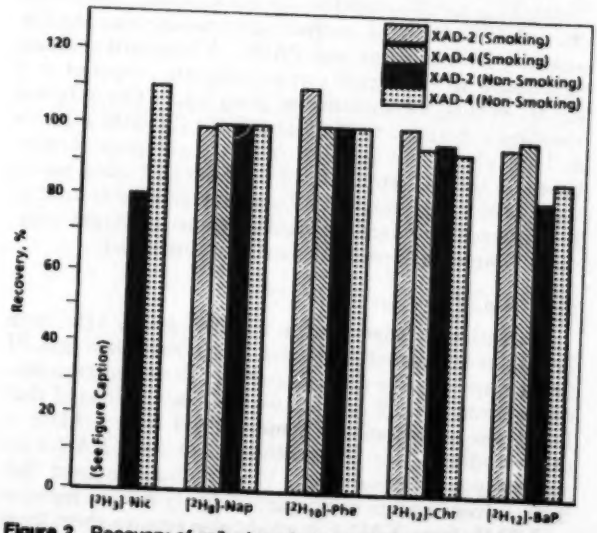

Figure 2. Recovery of spiked perdeuterated PAHs and nicotine from XAD-2 and XAD-4. [$^2H_{12}$]BaP, [$^2H_{12}$]benzo[a]pyrene; the remaining compounds are expressed as described in Figure 1. Vertical bars represent either the average recoveries from four experiments under smoking conditions or the single measurement from one experiment under nonsmoking conditions. [$^2H_3$]Nicotine recovery data in the smoking condition cannot accurately be calculated because of interference peaks.

ambient sampling temperature (38 °C). We used a quartz fiber filter and two XAD-2 traps in series to collect air samples. The results showed that less than 2% of the PAHs in the first XAD-2 trap broke through to the second XAD-2 trap. Since XAD-4 has more surface area than XAD-2, we would expect that XAD-4 can retain PAHs as well as XAD-2. Note that the recoveries of [$^2H_3$]nicotine could not be accurately addressed because of interference peaks detected in the samples collected in the presence of ETS. Since the nicotine levels found in the presence of ETS are much higher than the spiked [$^2H_3$]nicotine levels

(2 μg), the interference peak may be from the native nicotine. However, XAD-4 provided better recovery of [$^2H_3$]nicotine than XAD-2 in the absence of ETS, suggesting that XAD-4 is the preferred adsorbent for nicotine. Furthermore, XAD-4 collects PAHs with an efficiency comparable to XAD-2.

We have used either EI or PCI with GC/MS methods to analyze PAHs and nicotine. The methods were comparable for PAHs, but as expected, PCI was more sensitive to nicotine than was EI. This finding agreed with the other study that we conducted, which showed that the PCI method provides higher detection sensitivity for nitrogen heterocyclic compounds than does the EI method (*19*). Because high levels of nicotine were found in the samples collected under smoking conditions, both EI and PCI methods provided adequate detection sensitivity. In fact, in the sampling efficiency study, when the protonated molecular ion $(M + 1)^+$ of nicotine was saturated in some samples, a secondary ion mass of lesser intensity $(M + C_2H_5)^+$ was used for quantification. However, the more sensitive PCI method may be needed to determine nicotine in air samples containing less ETS than used in this study.

Conclusions

The following conclusions can be drawn from this study. The collection system, a quartz fiber filter and XAD-4 resin in series, can be used to collect PAHs and nicotine in indoor air with high efficiency. The extraction method, Soxhlet extraction with dichloromethane followed by ethyl acetate, can quantitatively remove both PAHs and nicotine from XAD-4 resin. The analysis method, PCI or EI with GC/MS operated in the SIM mode, can be used to determine both PAHs and nicotine.

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Registry No. XAD–2, 9060-05-3; XAD–4, 37380-42-0; quartz, 14808-60-7; naphthalene, 91-20-3; nicotine, 54-11-5; acenaphthylene, 208-96-8; phenanthrene, 85-01-8; anthracene, 120-12-7; fluoranthene, 206-44-0; pyrene, 129-00-0; benz[*a*]anthracene, 56-55-3; chrysene, 218-01-9; benzo[*a*]pyrene, 50-32-8.

Literature Cited

(1) Chuang, J. C.; Petersen, B. A. *Review of Sampling and Analysis Methodology for Polynuclear Aromatic Compounds in Air from Mobile Sources*; EPA/600/4-85/045; U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring Systems Laboratory, U.S. EPA: Research Triangle Park, NC, 1987.
(2) Lewtas, J.; Goto, S.; Williams, K.; Chuang, J. C.; Petersen, B. A.; Wilson, N. K. *Atmos. Environ.* **1987**, *21*, 443.
(3) Miller, M.; Alfheim, I. *Environ. Sci. Technol.* **1982**, *16*, 221.
(4) Chuang, J. C.; Mack, G. A.; Koetz, J. R.; Petersen, B. A. *Pilot Study of Sampling and Analysis for Polynuclear Aromatic Compound in Indoor Air*; EPA/600/4-86/036; U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring System Laboratory, U.S. EPA: Research Triangle Park, NC, 1987.
(5) Wilson, N. K.; Chuang, J. C. In *Polynuclear Aromatic Hydrocarbons, Proceedings, 11th International Symposium*; Lewis Publishers: London, in press.
(6) Burnekreef, B.; Boleij, J. S. M. *Int. Arch. Occup. Environ. Health* **1982**, *50*, 299.
(7) Repace, J.; Lowery, A. H. *Science* **1980**, *208*, 464.
(8) Alfheim, I.; Ramdahl, T. *Environ. Mutagen.* **1984**, *6*, 121.
(9) Lofroth, G.; Nilsson, L.; Alfheim, I. In *Short-Term Bioassays in the Analysis of Complex Environmental Mixtures III*; Waters, M. D., Sandhu, S. S., Lewtas, J.; Claxton, L., Chernoff, N., Nesnow, S., Eds.; Plenum Press: New York, 1983; p 515.
(10) Mumford, J. L.; Harris, D. B.; Williams, K.; Chuang, J. C.; Cooke, M. *Environ. Sci. Technol.* **1987**, *21*, 308.
(11) Hammond, S. K.; Leaderer, B. P., Roche, A. C.; Schenker, M. *Atmos. Environ.* **1987**, *21*, 457.
(12) Williams, D. C.; Whitaker, J. R.; Jennings, W. G. *EHP, Environ. Health Perspect.* **1985**, *60*, 405.
(13) Eatough, D. J.; Benner, C. L.; Bayona, J. M.; Caka, F. M.; Mooney, R. L.; Lamb, J. D.; Lee, M. L.; Lewis, E. A.; Hansen, L. D.; Eatough, N. L. Paper presented at the 4th International Conference on Indoor Air Quality and Climate, Berlin, West Germany, 17–21 August, 1987.
(14) Eudy, L. W.; Thome, F. A.; Heavher, D. L.; Green, C. R.; Ingebrethsen, B. J. In *Proceedings, 79th Annual Meeting of the Air Pollution Control Association*; Minneapolis MN, 22–27 June, 1986; Paper 86–38.7.
(15) Chuang, J. C.; Hannan, S. W.; Wilson, N. K. *Environ. Sci. Technol.* **1987**, *21*, 798.
(16) Wilson, N. K.; Kuhlman, M. R.; Chuang, J. C.; Mack, G. A.; Howes, J. E., Jr. *Environ. Sci. Technol.* **1989**, *23*, 1112.
(17) Oldaker, G. B., III; Conrad, F. C., Jr. *Environ. Sci. Technol.* **1987**, *21*, 994.
(18) Coutant, R. W.; Brown, L.; Chuang, J. C. *Atmos. Environ.* **1988**, *22*, 403.
(19) Chuang, J. C.; Mack, G. A.; Mondron, P. J.; Peterson, B. A. *Evaluation of Sampling and Analytical Methodology for Polynuclear Aromatic Compounds in Indoor Air*; EPA/600/4-85/065; U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring System Laboratory, U.S. EPA: Research Triangle Park, NC, 1986.

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